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Geologic Conditions Affecting Coal Mine Ground Control in the Western United States

By Gary P. Sames and Robert B. Laird



UNITED STATES DEPARTMENT OF THE INTERIOR

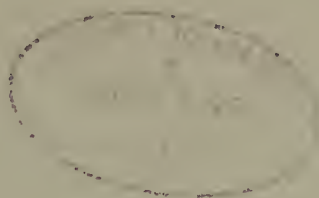


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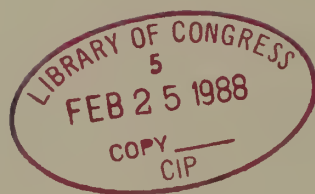
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CONTENTS

	<u>Page</u>
Abstract.....	1
Introduction.....	2
Background.....	2
Depositional hazards.....	3
Paleochannel deposits.....	3
Mining hazards.....	4
Field examples.....	7
Crevasse splay deposits.....	11
Mining hazards.....	11
Field examples.....	11
Flood basin and swamp deposits.....	12
Mining hazards.....	13
Field examples.....	14
Other depositional hazards.....	14
Lithofacies changes.....	14
Coal rolls.....	16
Bedding planes.....	16
Fossil casts.....	17
Structural hazards.....	20
Faults.....	20
Joints.....	20
Folds.....	24
Igneous dikes.....	24
Clastic dikes.....	26
Discussion.....	28
References.....	29

ILLUSTRATIONS

1. Map showing maximum extent of Western Interior Seaway.....	3
2. Idealized sequence of paleochannel formation during peat accumulation.....	5
3. Three most common paleochannel types found in western U.S. coal mines.....	6
4. Paleochannel that approaches and contacts coal top at high angle.....	8
5. Severely slickensided shale roof adjacent to paleochannel.....	8
6. Paleochannel that approaches coal top at low angle, seldom contacting it..	9
7. Massive supplemental roof support holding shale separated from overlying paleochannel.....	9
8. Abandoned paleochannel within coalbed.....	10
9. Area of high roof fall showing thin bedding in crevasse splay deposit.....	11
10. Buckling in crevasse splay roof rock, caused by horizontal stress.....	12
11. High, domed-shaped cavity in crevasse splay deposit at intersection roof fall.....	12
12. Desiccation cracks in flood basin deposit exposed in roof.....	13
13. Severely slickensided claystone roof typical of flood basin deposits.....	14
14. Roof cavity caused by fall of large western U.S. kettlebottom.....	15
15. Small kettlebottom showing slickensided root structure and coalified tree trunk.....	15
16. Moisture-sensitive claystone and roof failure between installed supports..	16
17. Normally flat-lying coalbed descending inferred sandstone beach ridge.....	17
18. Simple bedding separation in shale.....	18

ILLUSTRATIONS--Continued

	<u>Page</u>
19. Fossil worm burrow casts in sandstone.....	18
20. Dinosaur footprint cast (sandstone) in shale.....	19
21. Dinosaur trackway with many superimposed sandstone footprint casts separated from underlying shale by slickensides.....	19
22. Portion of mine map in area of intensive normal faulting with associated roof falls.....	21
23. Normal fault showing adjacent roof fractures and support.....	22
24. Normal fault showing little roof disturbance but with evidence of pressure along fault plane.....	22
25. Schematic of low-angle reverse faulting and failure above roof bolt anchorage horizon.....	22
26. Joint set unrelated to cleat in coalbed.....	23
27. Jointing in coalbed parallel to mining, which has caused pillar slabbing..	23
28. Pillar failure caused by jointing in coalbed.....	24
29. Small roof fall caused by closely spaced joints.....	25
30. Haulage entry in steeply pitching coalbed with updip floor rock mined for improved maneuverability.....	25
31. Closeup of igneous dike in coal rib showing effects of heat on coal.....	26
32. Several discontinuous igneous dikes cutting coalbed, with parallel fracturing in roof rock and coal.....	27
33. Clastic dike entering coalbed from floor.....	27

GEOLOGIC CONDITIONS AFFECTING COAL MINE GROUND CONTROL IN THE WESTERN UNITED STATES

By Gary P. Sames¹ and Robert B. Laird²

ABSTRACT

The Bureau of Mines recently initiated a study of geologic features that contribute to roof instability in western U.S. underground coal mines. The purpose of the study is to provide information for use in ground control planning and safety hazard reduction in that region, where mining activity has been increasing. Hazardous geologic conditions were surveyed in selected underground coal mines in Utah and Colorado, and both depositional and structural features were identified as potential ground hazards.

Although the conditions found do not differ in kind from hazardous geologic conditions in the Eastern United States, they do differ in intensity of occurrence and relative importance. Three depositional features dominate where unstable roof occurs in western underground coal mines: paleochannel deposits, crevasse splay deposits, and flood basin deposits. Three structural features identified as hazardous, but not so widespread or common as the depositional hazards, are faulting, jointing, and igneous intrusions. This survey establishes a foundation for future studies aimed at reducing and preventing ground control accidents in western coal mines.

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INTRODUCTION

Ground control accidents (consisting primarily of unexpected roof falls) are a major cause of fatalities in underground coal mining. Ongoing Bureau research into geologic conditions affecting coal mine roof stability has been concentrated in the Appalachian Coal Province and the Illinois Basin (hereafter referred to as the "East"). The research reported here is directed toward identifying the impact of geologic conditions found in western U.S. coalfields on the occurrence of unstable mine roof areas, and toward determining effective support techniques for their control.

Increased demand for the low-sulfur coal found in the Rocky Mountain Coalfields of the Western United States (hereafter referred to as the "West") has greatly increased underground coal mining

activities in that region. The coal industry, as a result, is contending with geologic conditions about which there is inadequate information in public domain mining literature. The Bureau, therefore, initiated this study to identify and document geologic features that may cause roof instability in western coal mines. The results presented here are based on work conducted under Bureau contract J0145032, through Goodson & Associates of Denver, CO. Details of this work are available through the National Technical Information Service (NTIS) and as a Bureau open file report (1).³ This work establishes a foundation for future studies aimed at reducing and preventing ground control accidents and injuries in western coal mines by avoiding or controlling hazardous geologic conditions.

BACKGROUND

Most western coals were deposited during the Upper Cretaceous and Lower Tertiary Periods, at least 180 million yr after the Pennsylvanian-age coals of eastern North America. The associated flora found as fossilized remains in Cretaceous-age deposits differs from that of the Pennsylvanian age. Cretaceous coals developed from a much more advanced flora. The horsetails (*Lepidodendron* and *Sigillaria*) and clubmosses (*Calamities*) dominant during the Pennsylvanian had by the Cretaceous Period declined to a position of minor importance (2). According to McGookey (3), the Cretaceous climate was warm and humid, probably much like that of the southern Atlantic coast of the United States today. Inland areas were covered by pine forests, and when conditions were favorable, large coastal areas were covered by deltaic and interdeltaic swamps, while the whole region was inhabited by dinosaurs. The swamps formed the extensive and sometimes very thick coalbeds being mined today.

Both eastern Pennsylvanian-age and western Upper Cretaceous-age coals are products of coastal plain depositional environments that were strongly influenced by major transgressions and regressions (expansions and contractions) of sea water. However, Western Interior Seaway transgressive and regressive cycles were generally more erratic and rapid than those in the East during the Pennsylvanian. As a result, Upper Cretaceous coalbeds generally exhibit greater lateral and vertical variability (4). Coal was deposited along the western shoreline as it fluctuated with the level of the Western Interior Seaway, a north-south-trending epicontinental sea that extended from western Utah east to the present-day location of the Mississippi River and from the Arctic Ocean to the Gulf of Mexico (5) (fig. 1).

³Underlined numbers in parentheses refer to items in the list of references at the end of this report.

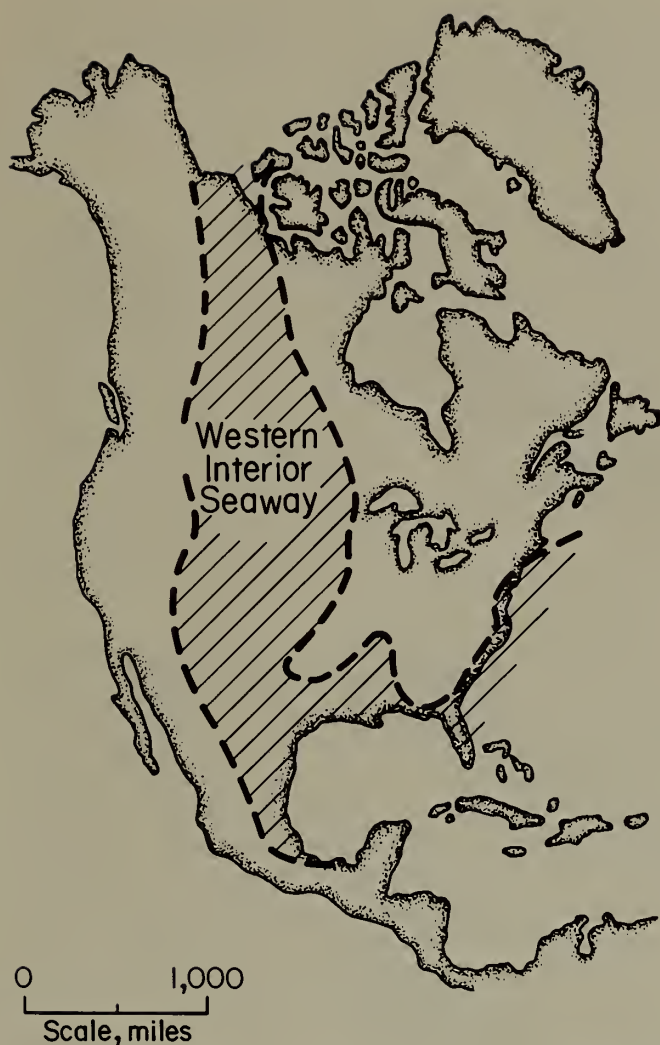


FIGURE 1.—Map showing maximum extent of Western Interior Seaway.

The close of the Cretaceous Period is marked by complete regression of the Western Interior Seaway and by the beginning of the Laramide Orogeny. Structural deformation throughout the Rocky Mountain region during the Laramide Orogeny produced a series of normal faults, creating a number of graben structures (depressed segments of the Earth's crust), in which some blocks of Cretaceous and older sediments were lowered relative to uplifted blocks of the same age. The graben structures define the intermontane basins where Cretaceous coalbeds are found today. Cretaceous sediments overlying the Laramide Orogenic belt that were not downfaulted into protected basins were eroded, supplying the clastic material for Tertiary sedimentation (3).

Coal deposition during the Tertiary Period occurred within the intermontane basins. Coal was deposited in freshwater swamps adjacent to the terrestrial fluvial channels (rivers and streams) that transported sediments from the surrounding Laramide orogenic highlands. The swamps were protected by levees from frequent incursions of flood waters, allowing large areas of stable peat accumulation. However, Tertiary coals are not currently mined underground in significant amounts and are generally of sub-bituminous or lignite rank because of their younger age and shallower depth of burial as compared with Cretaceous coal (6).

DEPOSITIONAL HAZARDS

This study indicates that paleochannel deposits cause the most common and severe roof instability problems in western coal mines. Crevasse splay deposits of thinly interbedded sandstone, siltstone, and mudstone, and swamp and flood basin deposits of thin coals and fine-grained sediments also cause roof instability.

PALEOCHANNEL DEPOSITS

Erosion of orogenic highlands and transportation of sediments during deposition of western coals occurred primarily through fluvial processes. Streams and rivers that carried sediments through the coal-forming swamps are often

recorded in the stratigraphic record and are visible in many underground coal mines as lenticular, lens-shaped deposits (commonly known as paleochannels) of sandstone or thin-bedded siltstone and claystone (abandoned channel fill).

Paleochannel deposits of sandstone are usually massive, crossbedded, medium to fine grained, well indurated, and well sorted. The basal sand may contain rip-ups, channel lag deposits, floating pebbles, and sole marks such as flute casts. Fining upward, stacked, and crossbedded sequences of sandstone, siltstone, and mudstone are commonly observed in the channel cross section (7).

Figure 2 is an idealized sequence of paleochannel formation during peat accumulation. In figure 2A, two active streams with natural levees form in a peat swamp. As time passes, both streams are affected by flooding and form overbank deposits of mud, clay, and silt (fig. 2B). In figure 2C, one stream channel is abandoned, infilled, and then buried by continued peat accumulation. The other stream continues to widen, is further affected by flooding, and develops channel lag (coarse rock fragments deposited in the most swiftly flowing part of the stream) and slump deposits. As the entire area is covered by water during a major transgressive cycle, the second stream channel is infilled (fig. 2D). The entire sequence is then buried by repeated episodes of sinking down of the Earth's crust and transgressions and regressions of the sea. Lithification of the sediments and coalification of the peat by burial results in the paleochannel features found in today's western coalbeds.

Many hazardous depositional and compactional conditions are associated with paleochannels. The three most commonly occurring paleochannel types found in western underground coal mines are depicted in figure 3. Channel A, formed contemporaneously with the peat and abandoned, was infilled with fine-grained sediments and then buried under continued peat accumulation. Both channels B and C formed after peat accumulation and shallow burial and consist mostly of sandstone. Channel B cut through the

overlying sediments and partially eroded the peat. Channel C partially cut through the overlying sediments but did not erode the peat.

Mining Hazards

Some characteristics common to paleochannels found in western coal mines are shown in figure 3. A typical paleochannel encountered during mining can include the main channel body, or a series of small channels, which may contact and sometimes replace the coal; adjacent coal splitting; coal thickening; mud slips; clastic dikes; slickensided planes; fractures; distorted bedding or slump deposits; and water (8). There are mining hazards associated with each of these characteristics.

The main channel body may exhibit several possible hazardous conditions. The entire channel interface with surrounding sediments is usually slickensided. Slickensides are highly polished, sometimes-striated surfaces caused by differential compaction and uneven loading (9). The slickensided channel boundary envelope constitutes a surface of weakness or lack of bonding, allowing the rock directly beneath and adjacent to the channel to separate as coal is mined. Coal streaks within the channel sandstone can also create planes of weakness that may lead to separation after mining. Jointing sometimes occurs in paleochannel sandstone and can result in blocklike failure when combined with bed separation. Other characteristics that are common to sandstone paleochannels but do not usually create roof fall hazards are channel lag and cross-bedding, the arrangement of minor beds or laminations at an angle to the main stratified unit (10). Cross beds with abundant mica or coal streaks can create delamination hazards.

Horizontal splitting of coalbeds by claystone partings in western coal mines can signify the proximity of a contemporaneous paleochannel. A coalbed split usually begins as a thin mud or clay parting, the result of sheet flood deposition of very fine sediment, several hundred feet from the paleochannel.

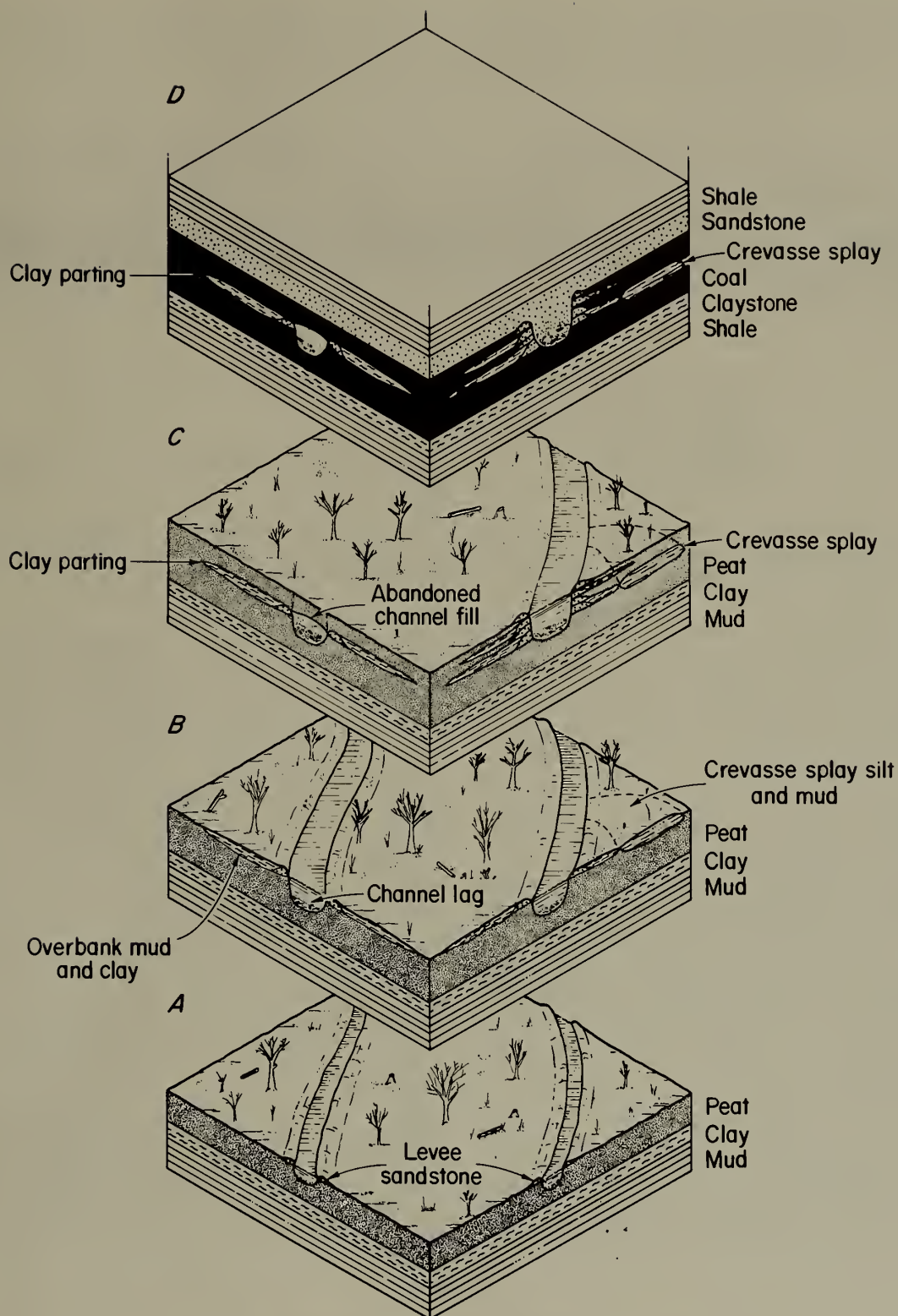


FIGURE 2.—Idealized sequence of paleochannel formation during peat accumulation. *A*, Two active streams with natural levees form in Cretaceous peat swamp; *B*, both streams are affected by flooding and form overbank deposits as time passes; *C*, one stream channel is abandoned as the other continues to develop; *D*, sequence is completed by marine transgression and burial.

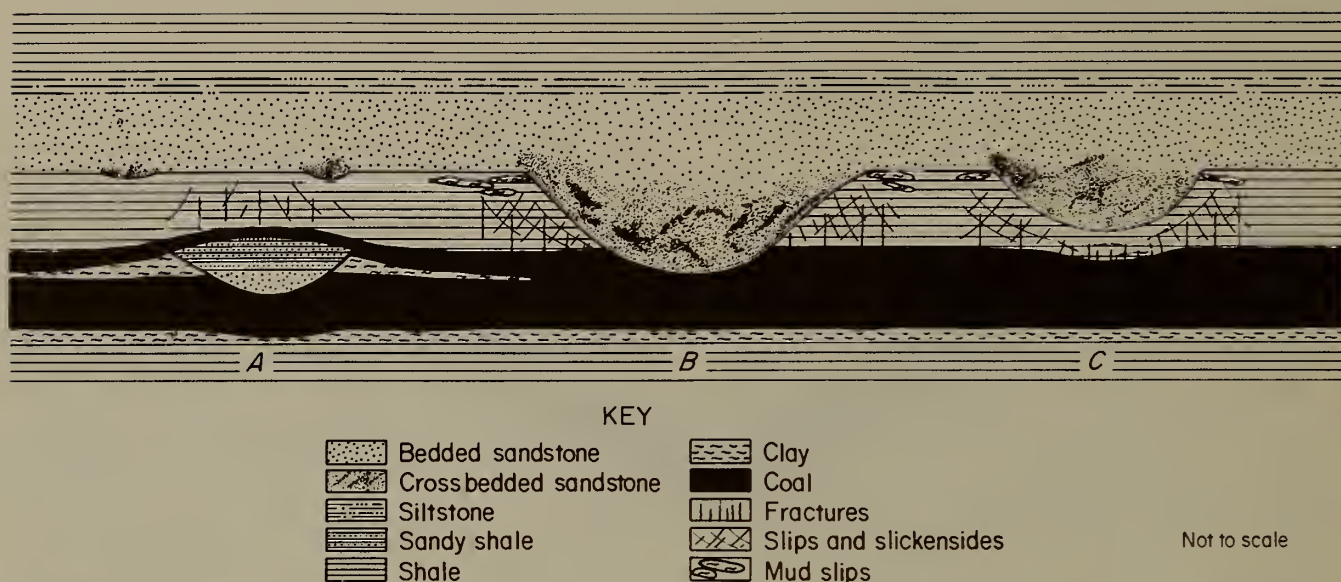


FIGURE 3.—Three most common paleochannel types found in western U.S. coal mines. A, Paleochannel formed contemporaneously with peat; B, paleochannel, formed after peat accumulation, that partially eroded the peat; C, paleochannel, formed after peat accumulation, that did not erode overlying sediments to the peat.

As mining progress toward the channel, the parting can thicken and separate the coalbed into two seams. If the split becomes uneconomical to mine, conditions in the roof can resemble those in figure 3A.

An increase in coal thickness may be noted when mining near a paleochannel. Differential compaction or uneven loading, which squeezes the soft peat from beneath the channel and swells it to either side, is commonly believed responsible for increases in adjacent coal thickness (11). No hazardous conditions are generally associated directly with increased coal thickness, but the increase indicates other disturbances in the surrounding strata.

"Mud slip" is a mining term used to describe a claystone or mudstone lens in the roof adjacent to a paleochannel (8) (fig. 3B-C). Mud slips are usually found on the inside meanders of paleochannels

and are commonly slickensided on both sides. Mud slips adjacent to paleochannels can cover a large area, depending on the size of the channel and meander bend. Mud slips can approach 30 ft along strike and can be 10 to 15 ft wide and several feet thick. However, most often mud slips are 3 to 4 ft in diameter and 2 to 5 in thick. When grouped together as in figure 3B and 3C, mud slips can create a large area that is subject to roof fall.

Clastic dikes adjacent to paleochannel deposits are compactional injections of soft sediment into ruptures in the coal during or after the coalification process (12). Clastic dikes occur both parallel and perpendicular to paleochannel deposits in a linear to curvilinear trend (13). The more common structural occurrences of clastic dikes and their effects on the roof are discussed more fully in a later section.

Abundant slickensides occur adjacent to paleochannels, caused by differential compaction of sand and adjacent finer grained sediments. Because they have very little cohesive strength, slickensides are planes of weakness that facilitate roof failure. They are associated with all three paleochannel types shown in figure 3. In their most common form, slickensides adjacent to paleochannels occur in two basic orientations: parallel and perpendicular to the main channel body (fig. 3B). These orientations create wedges of roof prone to failure at their slickensided margins, creating falls that are commonly known as "horsebacks" by miners.

The frequency of fractures in the roof can increase as a paleochannel is approached (8, 14). Fractures are often visible in the roof as "goatsbeard," a mining term used to describe the crystallization of gypsum or anhydrite from water seepage. The fractures, shown associated with all three paleochannel types in figure 3, can cause blocklike failure of the roof.

Distorted or slump bedding sometimes occurs adjacent to paleochannels. Distorted bedding is the result of differential compaction of sediments. Slump bedding is evidenced by discrete blocks of rock with rotated bedding relative to the surrounding rock. Slump bedding is the result of mass movement through rotational sliding of the channel bank. Slickensides and fractures associated with both distorted and slumped bedding cause mining hazards and change the roof bolt anchorage characteristics of the roof.

Paleochannels are often the source of water migration into the mine (8). Adverse conditions caused by water seepage from paleochannels include weakening and deterioration of roof rock, weathering of joints and fractures, and

lubrication of slickensides. The presence of excessive moisture tends to intensify the effects of any other adverse conditions already present.

Field Examples

Figure 4 shows a typical paleochannel in western coal mines, which approaches and contacts the top of the coalbed at a high angle. This situation illustrates the difficulty in supporting finer grained sediments (in this case a dark gray shale) adjacent to a sandstone paleochannel. The roof adjacent to the channel progressively failed because of slickensides both within the shale and at the channel boundary. The roof bolts nearest the rib were anchored in the channel sandstone, but the slickensided shale around them failed. The bolts installed in the remaining width of the entry in figure 4 were anchored within the shale and fell with it. Although this roof failed progressively, the potential for a sudden, massive fall was present. The beginning of roof rock failure between closely spaced supports in severely slickensided shale adjacent to a sandstone paleochannel is shown in figure 5.

Figure 6 shows a typical paleochannel approaching a coalbed at a low angle, seldom contacting it. The hard silty shale underlying the massive channel sandstone is highly fractured. The shale separated from the sandstone, falling between the bolts, and breaking the metal straps. Supplemental support (steel straps, wood posts, and crossbars) were installed in the main haulage entry under the channel to control the shale. Separation from the sandstone still occurred, but the supplemental support maintained the roof for the remaining width of the channel (fig. 7).

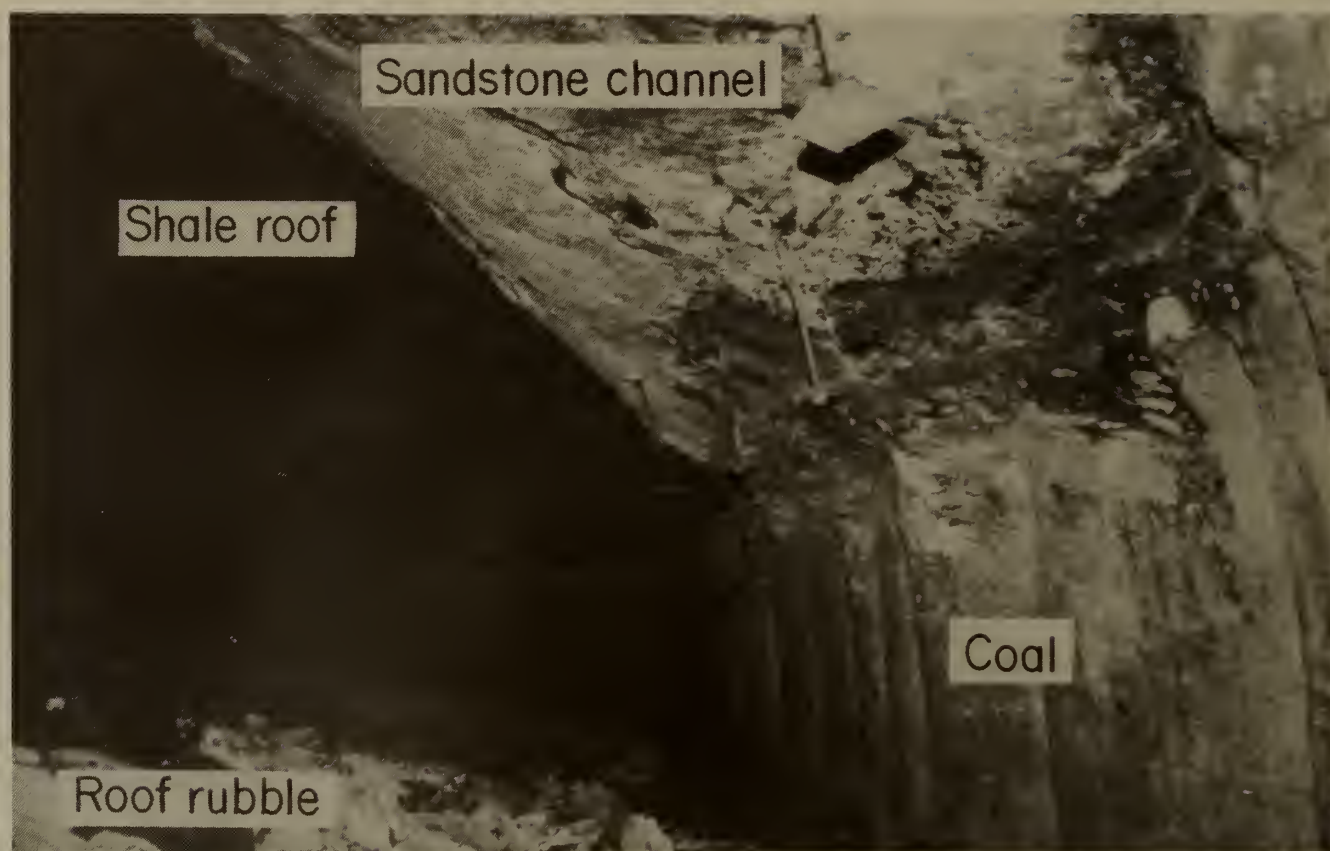


FIGURE 4.—Paleochannel that approaches and contacts coal top at high angle. Note adjacent shale roof failure.

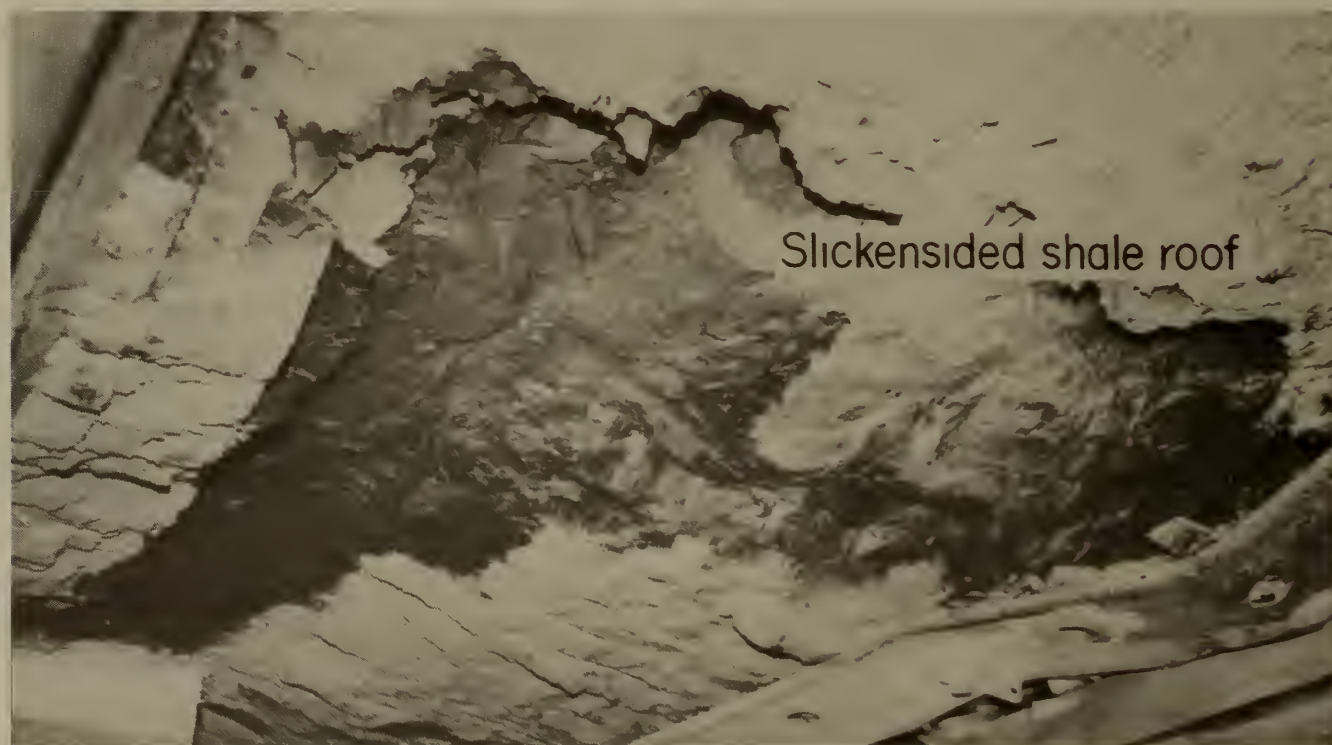


FIGURE 5.—Severely slickensided shale roof adjacent to paleochannel.



FIGURE 6.—Paleochannel that approaches coal top at low angle, seldom contacting it, with fractured and unstable underlying shale.

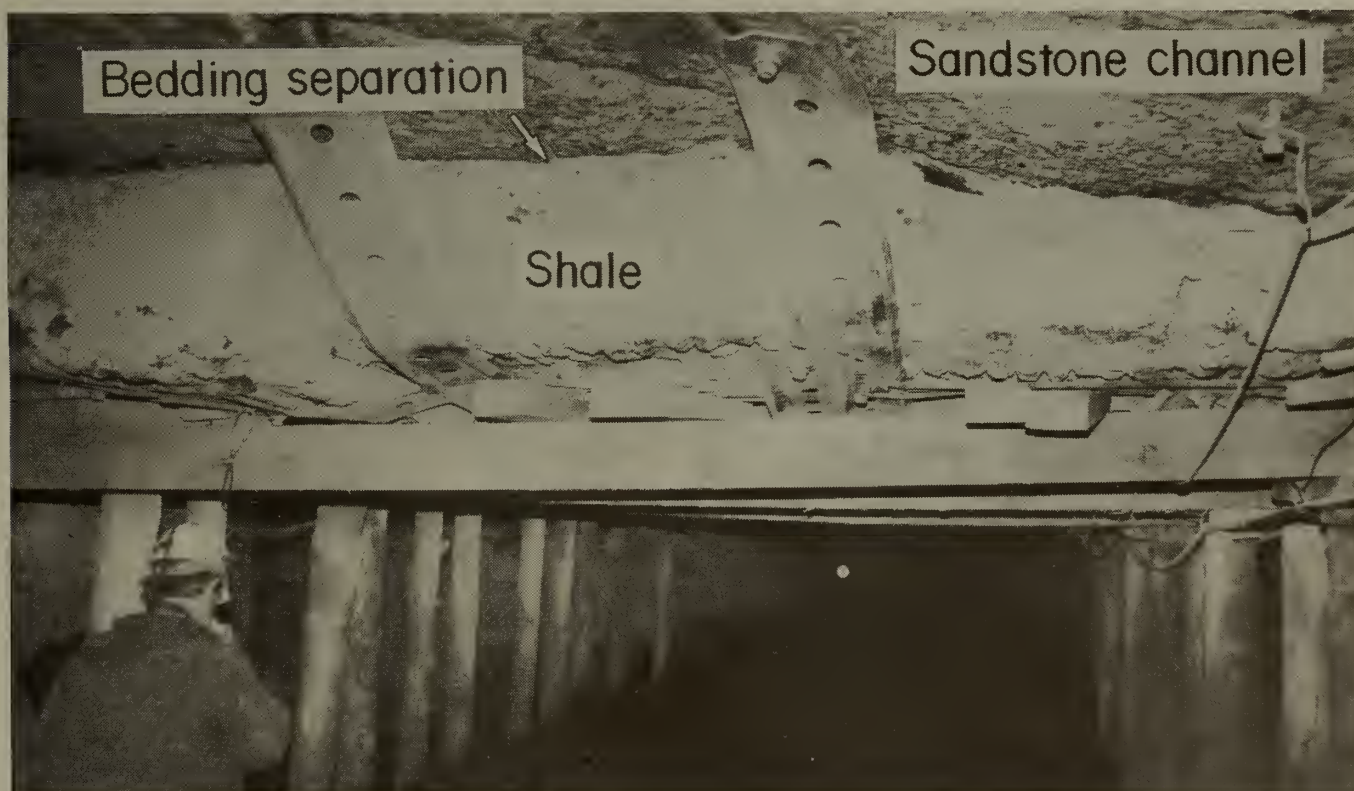


FIGURE 7.—Massive supplemental roof support holding shale separated from overlying paleochannel.

Figure 8 shows an abandoned channel that was infilled, then buried by continued peat accumulation (similar to that in figure 3A). This channel is exposed in a crosscut by a roof fall that included the overlying rider coal. A finding-upward sequence is apparent, grading from a massive, well-sorted sandstone, to siltstone, then mudstone, and back into coal. The sandstone is jointed

and weakened by carbonaceous bedding laminations. The rider coal presents the most hazardous condition in this situation because of poor bonding between it and the overlying and underlying strata. Anchorage of the roof bolts below the rider contributed directly to this roof fall, which included the top of the rider coal.



FIGURE 8.—Abandoned paleochannel within coalbed.

CREVASSE SPLAY DEPOSITS

Crevasse splay deposits of interbedded sandstone, siltstone, and mudstone adjacent to paleochannel trends are common in the West. Rivers at flood levels scour channels or crevasses through the levees. Lobes of sands and fines are then deposited where the flood water spreads into the adjacent basin. The sand is of the same composition as the main channel, but is often restricted in thickness, resulting in thin sand sheets that are dispersed in a lobate pattern. Once indurated, the sandstone sheets are separated, in a vertical sequence, by thin siltstone and mudstone laminations (15-16).

Mining Hazards

Crevasse splay deposits occur above the coalbed in most mines in the West. Crevasse splays contribute most significantly to mine roof instability when they are within 6 to 10 ft of the top of the coalbed and therefore constitute a part of the immediate roof (17). The thin, incohesive nature of crevasse splay bedding commonly causes delamination of the roof. Massive falls extending above the anchorage horizon sometimes result from this condition.

Observations made in this study indicate that crevasse splay roof becomes less stable with increasing overburden thickness. In mines where the overburden exceeded approximately 1,500 ft, roof of thinly laminated sandstone, siltstone, and mudstone became highly unstable. This effect is especially evident in intersections. The thin, brittle laminations of the crevasse splay appear to deform and fracture under the load, sometimes resulting in large and severe roof falls.

Field Examples

Figure 9 shows a crevasse splay deposit exposed in a high roof fall. The thinly laminated, brittle nature of the deposit

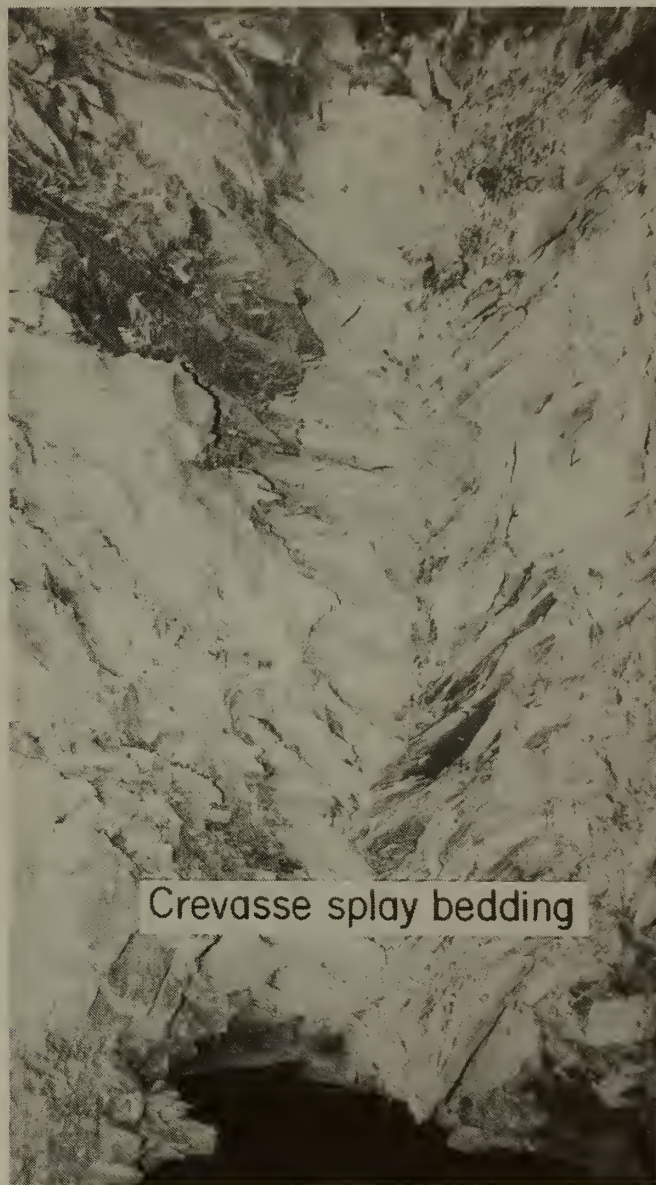


FIGURE 9.—Area of high roof fall showing thin bedding in crevasse splay deposit. Note evidence of pressure deformation.

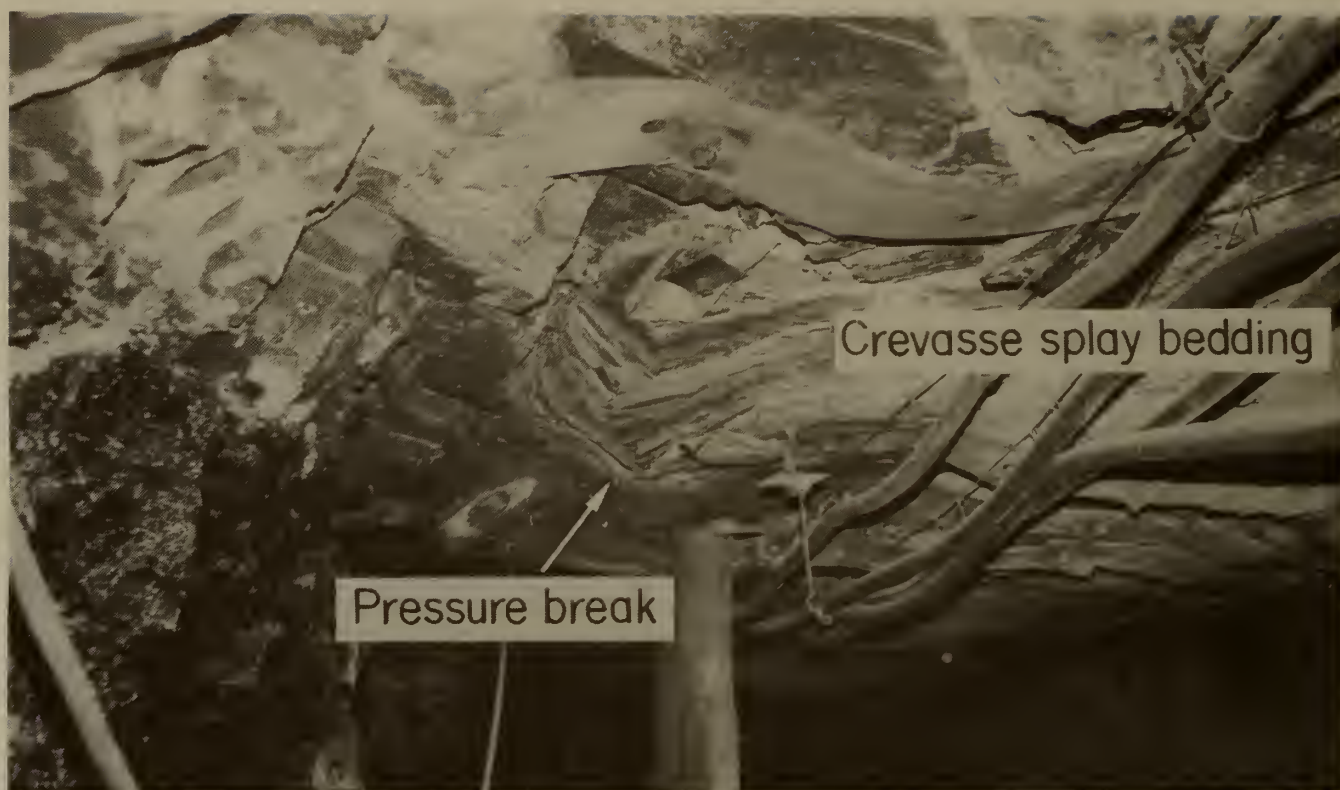


FIGURE 10.—Buckling in crevasse splay roof rock, caused by horizontal stress.

is evident. Figure 10 shows failure believed to be induced by high horizontal pressures. The roof strata have buckled, requiring additional support. Control of this type of failure is difficult. The roof failure effectively interrupts the continuity of the roof span and will eventually require more artificial support. Figure 11 illustrates another common roof fall in crevasse splay deposits: a high, dome-shaped fall. Although this may be an extreme example (the photograph was taken above the coal on top of a canopied support), it shows the bedded nature of crevasse splays and the scale of roof fall problems they can cause.

FLOOD BASIN AND SWAMP DEPOSITS

Flood basin deposits are generally fine-grained sands, clays, and silts. They are interlaminated, cross laminated, and often contain desiccation cracks (fig. 12). Flood basin deposits are often burrowed and rooted. Under suitable conditions, peat is deposited in flood basin swamps (7). Flood basin deposits



FIGURE 11.—High, domed-shaped cavity in crevasse splay deposit at intersection roof fall.

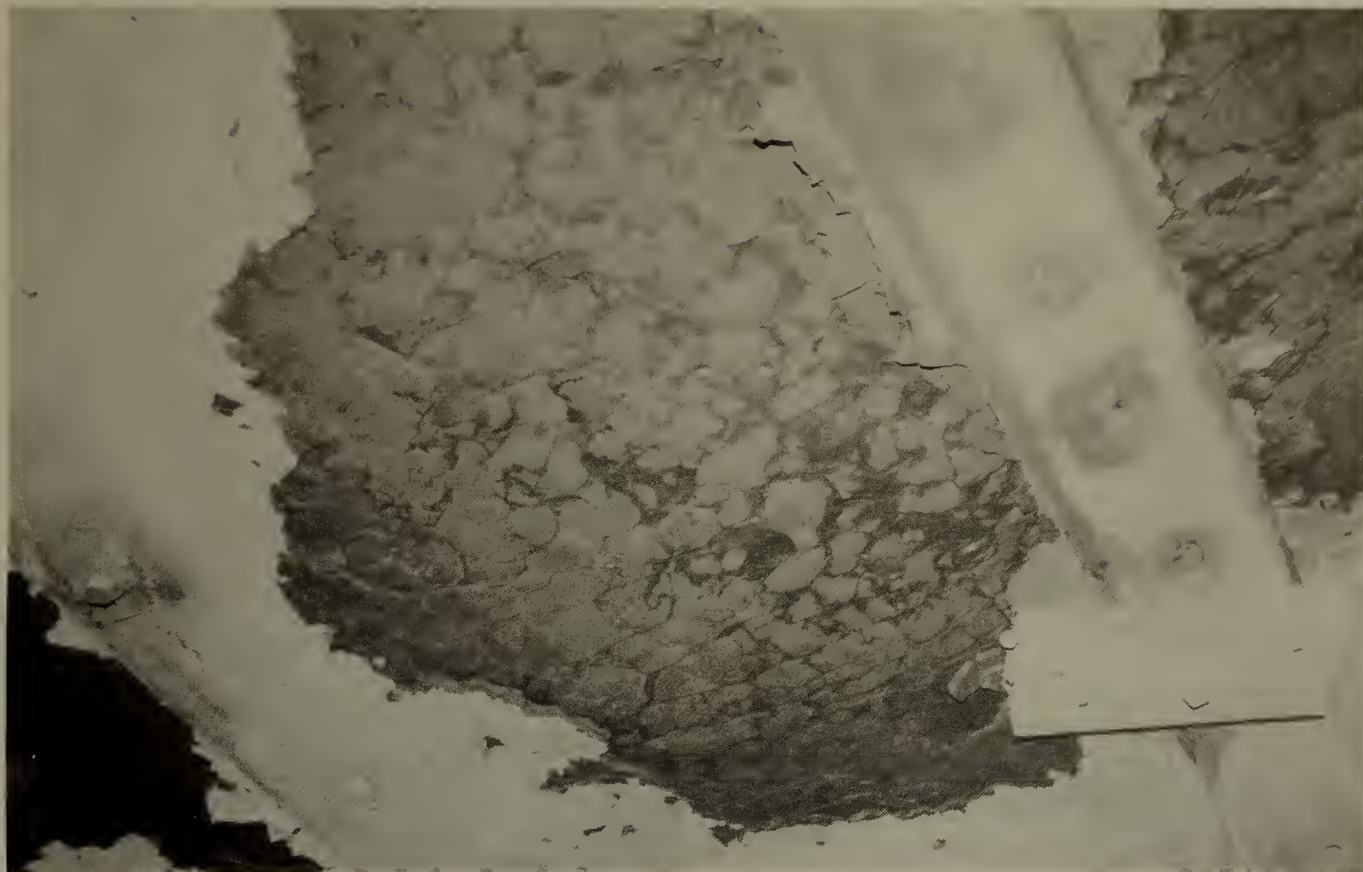


FIGURE 12.—Desiccation cracks in a flood basin deposit exposed in roof.

commonly form shale, claystone, and carbonaceous mudstone roof in western coal mines (18). The shales often grade upward into overlying swamp deposits of claystone, rooted mudstones, and thin coals or rider seams.

Mining Hazards

The finest grained flood basin deposits, claystones and mudstones, generally contain the features that cause the most common problems in this type of roof: slickensides, "kettlebottoms," rider seams, and fissile bedding. The sensitivity of most claystones to moisture adds to the roof support problems.

Slickensides, described previously, are usually more prevalent in mudstone and claystone. In areas of claystone immediate roof, many small slickensided planes can weaken the whole rock fabric, making support difficult, as the rock falls between roof bolts (19).

Kettlebottoms in western coal mines are quite different from those that commonly occur in the East. An eastern kettlebottom is defined as a columnar mass of rock (the preserved cast of an ancient tree stump) embedded in the normal coal mine roof strata and separated from them by a surrounding coal ring and slickensides (20). A western kettlebottom, on the other hand, is more a result of the tree root structure than of the trunk itself. The root systems of the trees that grew in the Cretaceous swamps of the West resulted in slickensides that radiate from the base of the tree. Therefore, kettlebottoms in the West fail at the slickensided boundaries of the structure in a concave upward circle, forming an inverted, funnel-like cavity in the roof.

Rider seams are common in swamp-type deposits. A rider seam is typically a thin, discontinuous coalbed above the coalbed being mined. When the interval

between the rider seam and main coal-bed thins, the rider forms a plane of weakness above the roof-bolting horizon, which can result in massive falls (21).

Deterioration of moisture-sensitive claystone and shale is usually a time-dependent phenomenon, with slow slaking of the roof during the dry winter season, and quickening deterioration during the more humid summer conditions (22). Deterioration caused by moisture can lead to a loss of mechanical roof bolt tension. The resulting roof failure by attrition increases debris on the mine floor, resistance to ventilation airflow, and in extreme cases, pillar height, with resultant pillar instability.

Some fossiliferous shales associated with swamp deposits are highly fissile. Shales of this type often split away from the roof between installed support, creating scattered, small roof rockfall hazards from hanging slabs.

Field Examples

Figure 13 shows an example of severely slickensided claystone roof typical of flood basin deposits.

Figure 14 shows a roof fall cavity caused by a very large western kettlebottom. This kettlebottom was approximately 16 ft in diameter, but others ranged down to 10 in. in diameter (fig. 15). Western kettlebottoms are difficult to distinguish from the normal mine roof in many cases. The only indication of their presence is often a slickenside that may be indistinguishable from many others. However, when a kettlebottom is identified, others should be suspected in the vicinity.

Deterioration of moisture-sensitive shale and claystone roof is a well-documented phenomenon in eastern coal mines. Figure 16 shows an example of this problem in a western mine. Moisture deterioration of the claystone roof resulted in progressive failure between the installed supports, up to a higher, more resistant strata. As is evident, this type of



FIGURE 13.—Severely slickensided claystone roof typical of flood basin deposits.

failure creates obstructions in haulage and ventilation entries and requires constant maintenance.

OTHER DEPOSITIONAL HAZARDS

Other, less common, but often severe instability problems not necessarily related to any one depositional condition are caused by lithofacies changes, coal rolls, bedding planes, underclays, and dinosaur footprint casts.

Lithofacies Changes

A particularly hazardous type of western coal mine roof is characterized by interfingering lithofacies changes (adjacent deposits of differing rock types). In general, lithofacies changes occur in areas of a delta plain that were periodically inundated or exposed by transgressing and regressing marine

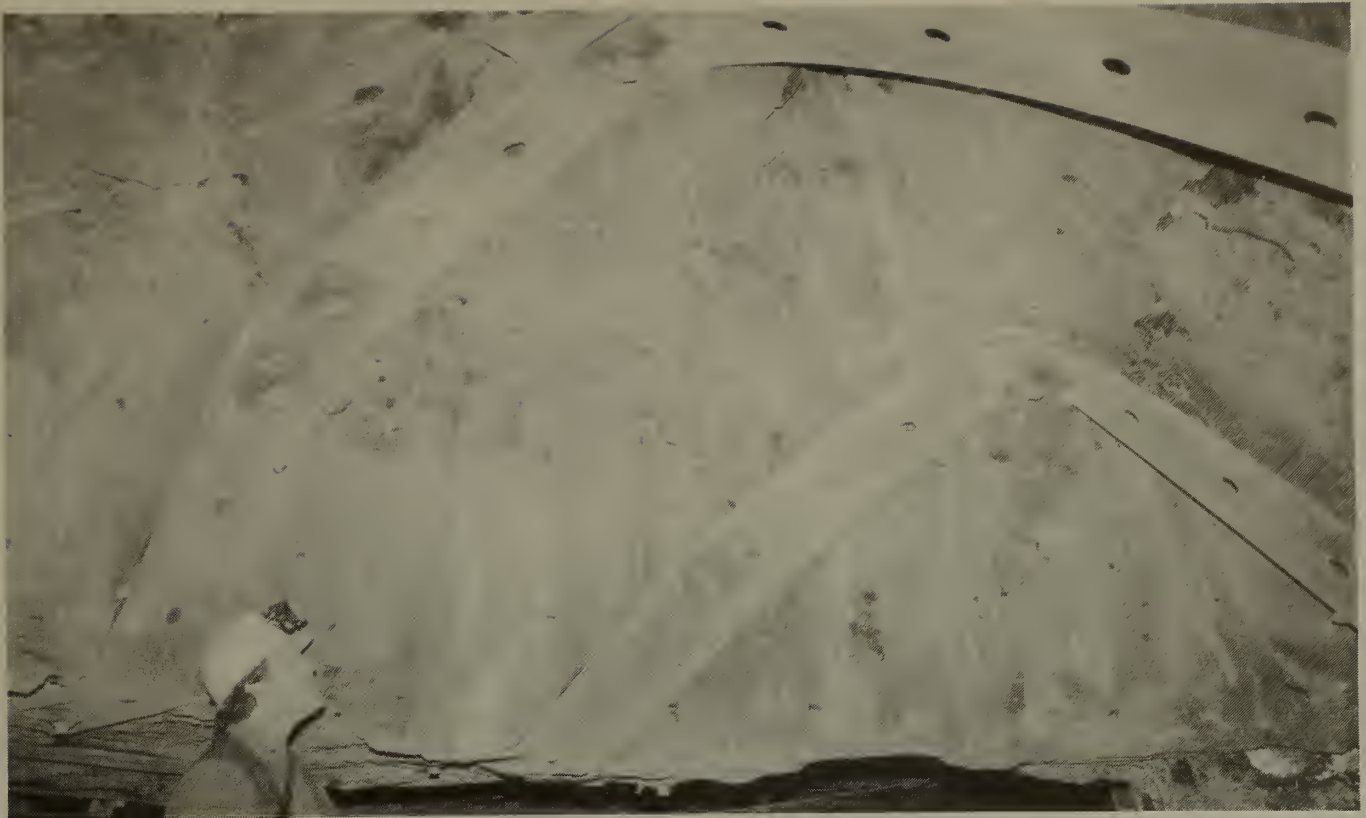


FIGURE 14.—Roof cavity caused by fall of large western U.S. kettlebottom.

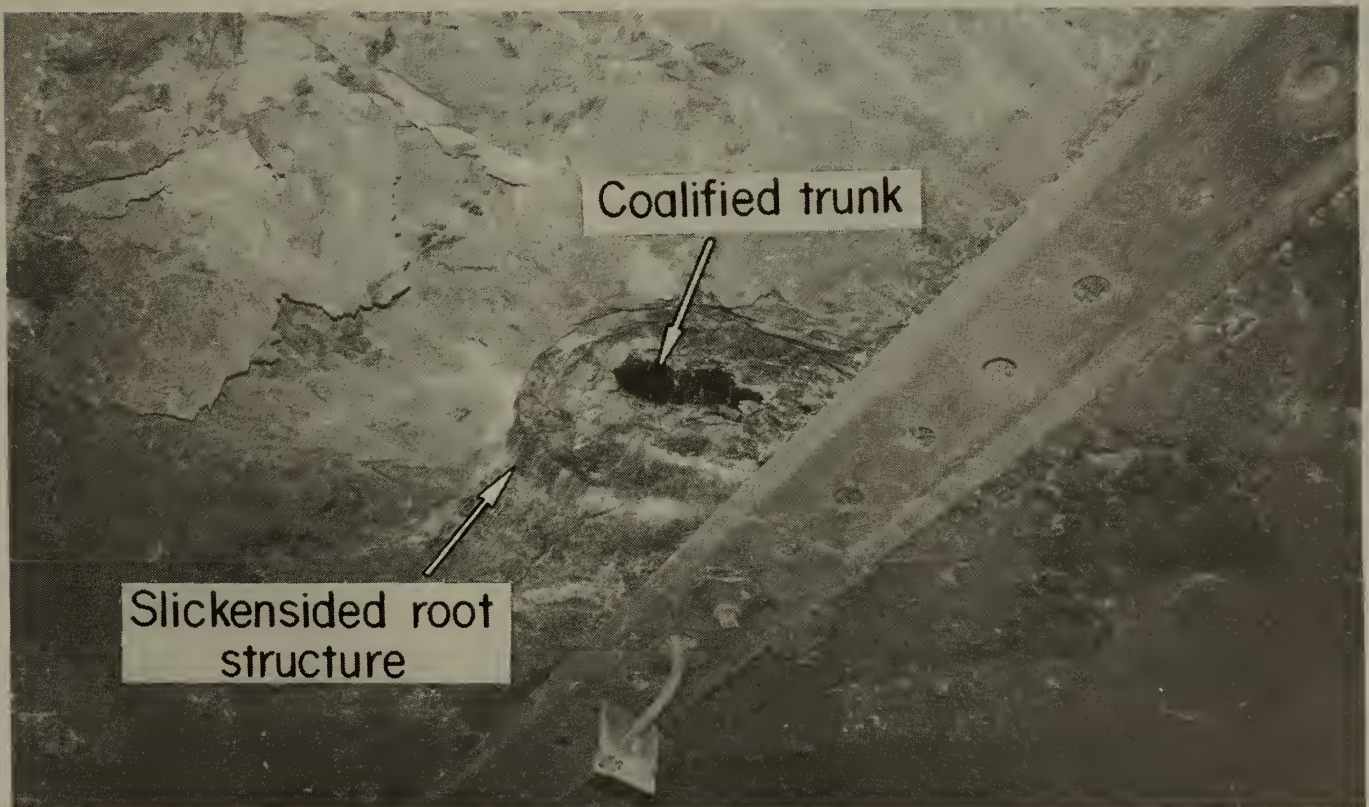


FIGURE 15.—Small kettlebottom showing slickensided root structure and coalified tree trunk.

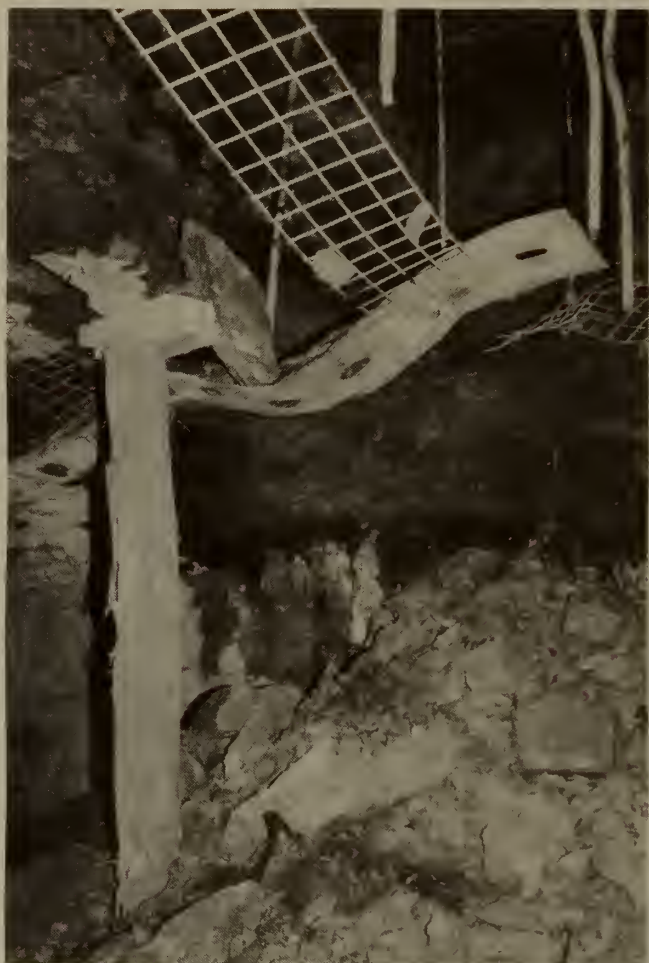


FIGURE 16.—Moisture-sensitive claystone roof failure between installed supports.

waters, resulting in fine-grained sediments being deposited adjacent to coarse-grained ones. Crevasse splay deposits and shifting distributary channels also result in this depositional condition (11, 21).

Examples of the hazards caused by lithofacies changes are presented in the sandstone channel illustrations (figs. 2-7), where two differing rock types deposited adjacent to one another have differing rock properties. As in the sandstone channel example (fig. 2), if one unit compacts more than the other, slickensides, distorted bedding, and some fracturing will likely occur in the more compactible unit. Also, a less compactible rock unit, such as a sandstone lens surrounded by shale, will have compactional deformation on all sides (23-24).

In general, wherever the roof rock type in a mine changes abruptly, the presence of adverse geologic structure and changing roof bolt anchorage characteristics should be suspected.

Coal Rolls

In western underground coal mines, a coal roll, as defined by Bunnell (25), is "an undulation in the coal seam." The coalbed undulates and may thin in response to local thickening in the floor. Bunnell offers as a likely explanation for coal roll formation the imbricately structured beach ridges that are produced by high-energy waves. Peat deposits superimposed on the beach ridges result in the formation of a coalbed that is draped over the beach ridges.

Figure 17 shows an entry in a mine that operates in a coalbed with a gentle regional dip. In a local area of this mine, the coalbed is alternately rising and descending over inferred beach ridges. In figure 17, the coalbed is believed to be descending the steep face of a sandstone beach ridge. Production problems are posed by the abrupt, steep grades, which make movement of machinery more hazardous and difficult. Water often accumulates in the troughs, adding to haulage problems. Previously described differential compaction conditions can occur at the apex of the beach ridges.

Bedding Planes

A common adverse geologic condition in western coal mines is weak bonding along bedding planes within the roof rock. As has often been documented, a relatively small piece of rock delaminating from the roof can prove dangerous. Bedding planes represent planes of weakness caused either by two periods of deposition of like sediments separated by a time lag or by deposition of two different sediment types (10). Bedding in the common roof rock types can range from thick-bedded sandstone to thinly bedded crevasse-type deposits to extremely fissile fossiliferous shales.



FIGURE 17.—Normally flat-lying coalbed descending inferred sandstone beach ridge.

The most hazardous occurrences of this type are in the previously discussed crevasse splay deposits. Fissile bedding in fossiliferous shales is also hazardous, with many loose overhanging slabs common in this roof type. Constant attention is required to keep these loosely hanging slabs scaled or supported. Figure 18 shows an example of bedding separation in shale.

Fossil Casts

Two types of fossil casts were observed in western mines: worm burrows and dinosaur footprints. Worm burrows, trace fossils of a burrowing marine worm, are more a curiosity than a mining hazard. Figure 19 shows a group of burrows observed beneath the silicified bark of a tree branch or trunk. Dinosaur footprint casts, however, are more common. Most dinosaur footprints consist of three forward toes with one rear "thumb" (26) (fig. 20), although four-toed footprints

have been observed. Footprint trace fossils developed where dinosaurs crossed the spongy, uncompacted peat of the swamp. The weight of the animals caused the peat to compact. To the extent that the peat was unable to rebound, a depression was formed that could later be infilled by other sediments, commonly sand (27). Because the sandstone of the footprints is usually part of an overlying sandstone unit, dinosaur footprint casts are not easily separated from the roof. However, in rare cases, they do separate from the roof and fall. Also, the underside of the footprint cast is usually a slickensided surface that allows any underlying rock to fall. Figure 21 shows an area of repeated dinosaur movement with many footprints superimposed. The footprints can be distinguished by their bulging downward surfaces. The 1-ft-thick fossiliferous shale immediately above the coal separated and fell from the slickensided footprints.

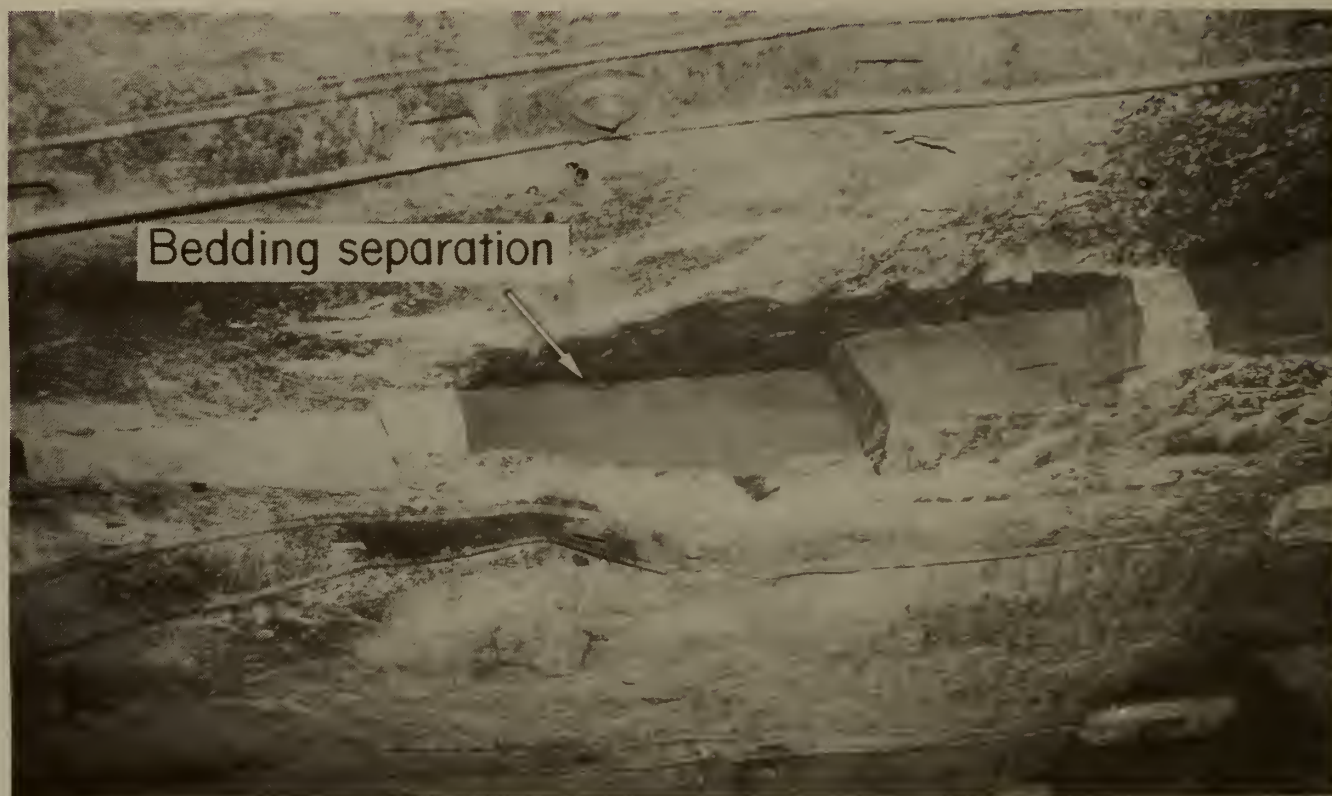


FIGURE 18.—Simple bedding separation in shale.



FIGURE 19.—Fossil worm burrow casts in sandstone immediately overlying a coalbed.

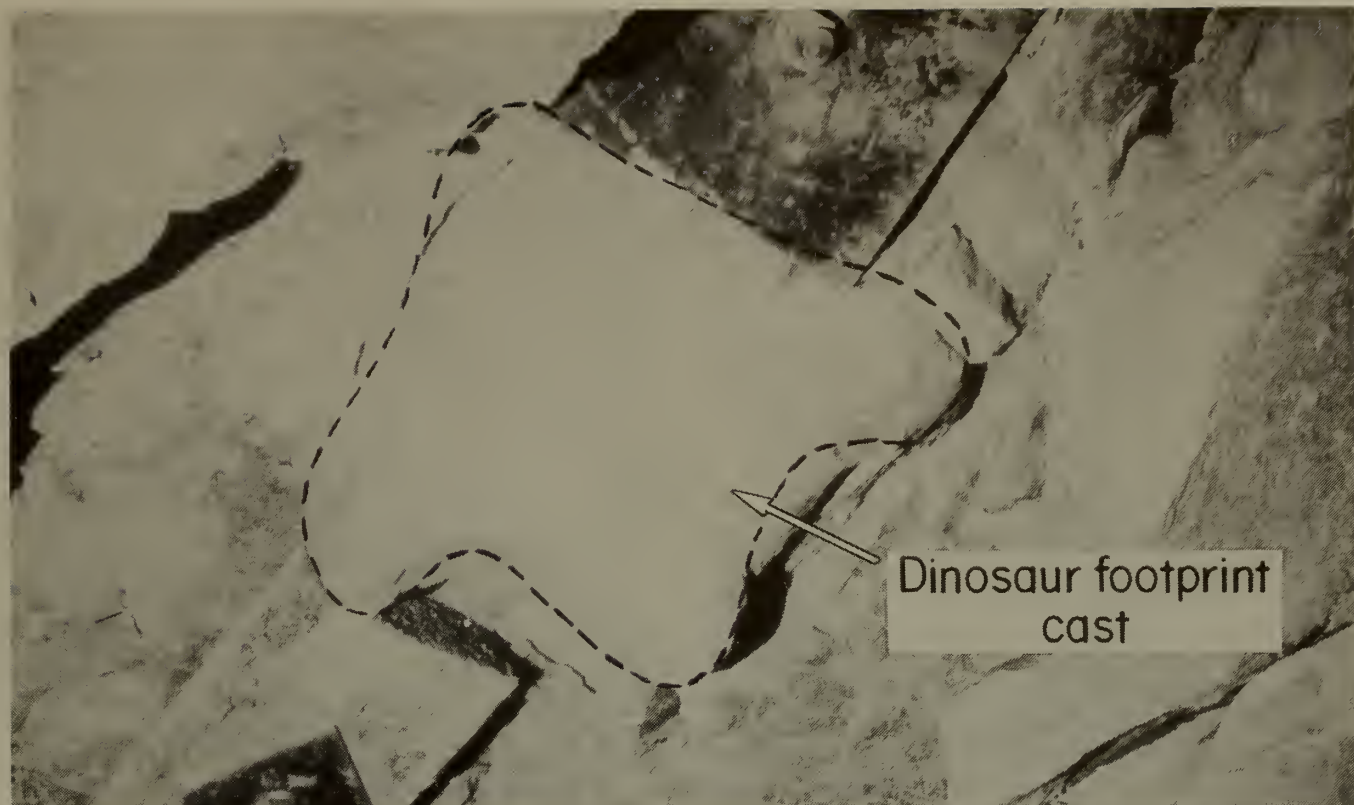


FIGURE 20.—Dinosaur footprint cast (sandstone) in shale. Note the characteristic three forward toes and one rear thumb.

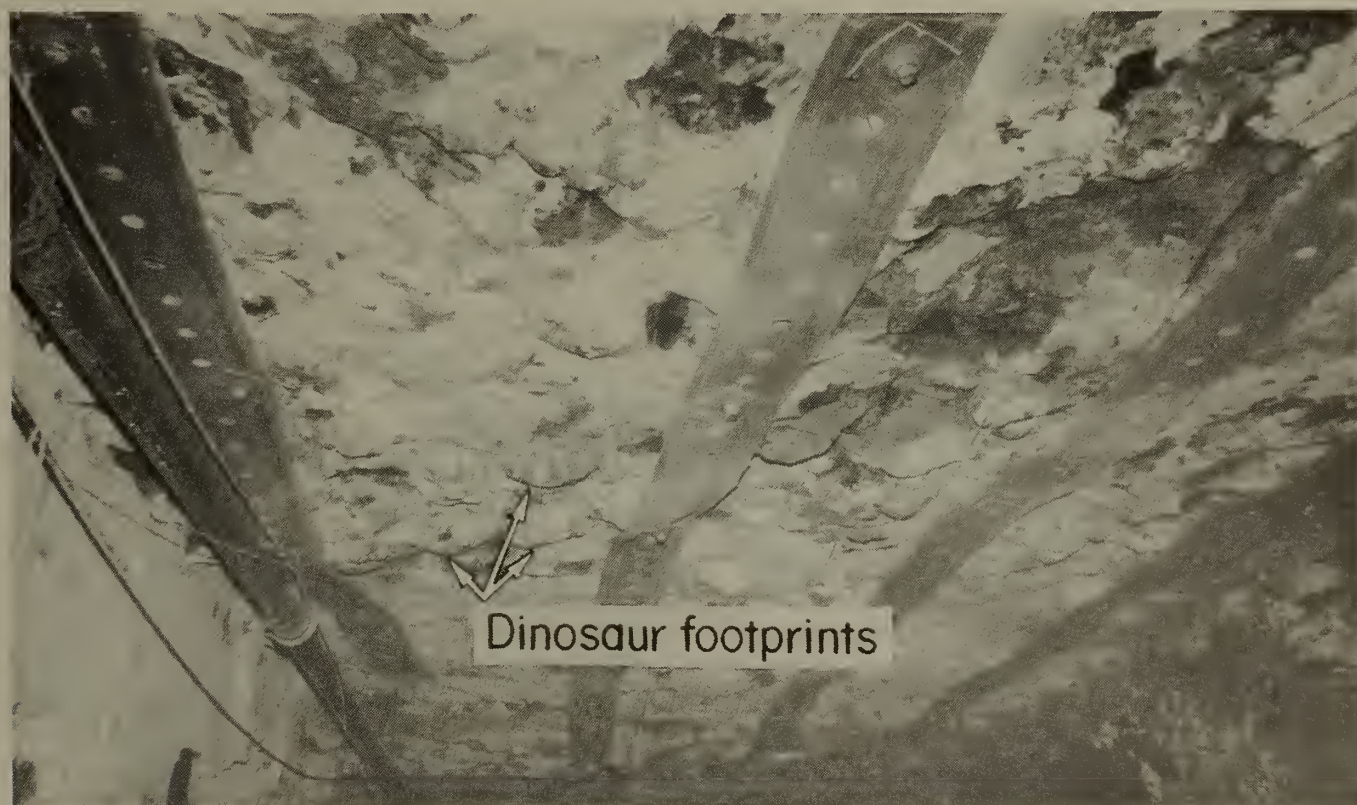


FIGURE 21.—Dinosaur trackway with many superimposed sandstone footprint casts separated from the underlying shale by slickensides.

STRUCTURAL HAZARDS

Hazardous structural conditions are not as common as depositional hazards in western underground coal mines. The most commonly encountered structural hazards are faults and joints. Folds, while not as common as faults or joints, can also present serious mining difficulties. Two other minor structural hazards that should be recognized are igneous intrusions and clastic dikes.

FAULTS

Faults are fractures or fracture zones in the rock strata along which there has been displacement of the two sides relative to one another and parallel to the fracture(s) (10). Faults are classified by the direction and angle of their movement. Several types of faults (normal, reverse, and strike-slip being the most common) occur in western coalfields with varying amounts of displacement. However, normal faulting, with the down-thrown block on the downdip side of the fault, was the predominant type encountered during this study.

Minor to severe ground control problems are associated with faults in western coal mines. Many faults observed during this study had displacements of only several inches and caused only minor ground control problems. In another instance, a fault zone 120 ft wide, with many closely spaced fault planes, vertically displaced the coal 18 to 30 ft and required rock tunnel development through severely broken roof to reach adjacent reserves.

Figure 22 shows a portion of a mine map in an area of intensive normal faulting. These faults all follow a distinct trend, and are associated with many roof falls, as indicated on the map. Displacement along most of these faults is between 3 and 5 ft, with several faults splaying into two or more distinct fault planes. Figure 23 shows one of the faults mapped in figure 22. This fault is nearly vertical, with approximately 3.5 ft of displacement. Although roof disturbance is minimal in this area, additional support is necessary on each side of the fault because of increased fracturing of the roof.

Figure 24 shows a less steeply inclined fault with approximately 1 ft of displacement. There is little of the usually associated adjacent roof disturbance, but the difficulty in penetrating the fault zone with a roof bolt drill indicates that there is active pressure being exerted along the fault. Two drill steels that were bound in the roof by the fault are visible in the figure.

Another less common, but possibly more hazardous fault type that occurs in western coal mines is the low-angle reverse fault. Figure 25 depicts this type of occurrence in a mine, with an associated roof fall. The low angle of the fault plane keeps it subparallel to the coalbed for an extended distance into the roof. In this example, as is common with this type of fault, the roof failed after the fault extended above the roof bolt anchorage horizon, but failure can also occur before installation of permanent support. Low-angle reverse faults generally cause more disturbance in the surrounding roof rock than do normal faults.

JOINTS

Joints are divisional planes or surfaces in the rock strata along which there has been no visible movement parallel to the plane or surface (10). Jointing in western coal mines affects both rib and roof control. The effects of jointing vary with joint patterns, joint density, and the lithology of the affected strata.

Prominent jointing within the coalbed that is unrelated to original cleat sometimes occurs in western coal mines (28). Figure 26 shows a joint set in a coalbed. Prominent jointing in the coalbed, when parallel to the direction of mining, can cause pillar slabbing that results in widening of the mine opening, creating a larger span to support (fig. 27). Jointing in the coalbed at an angle to mining is less detrimental to ground control but can still result in pillar failure at the corners and the need for additional roof support (fig. 28).

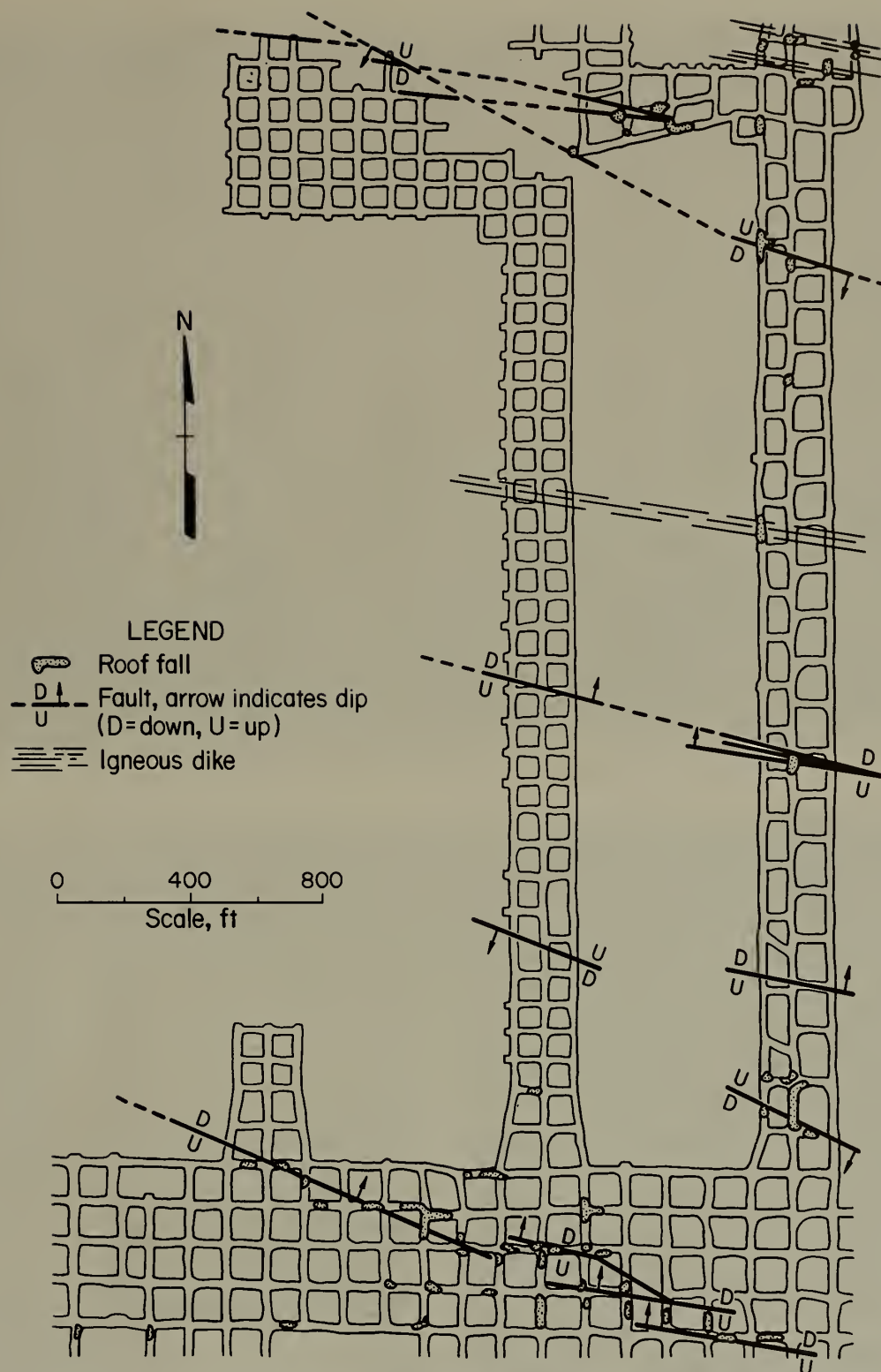


FIGURE 22.—Portion of mine map in area of intensive normal faulting with associated roof falls.

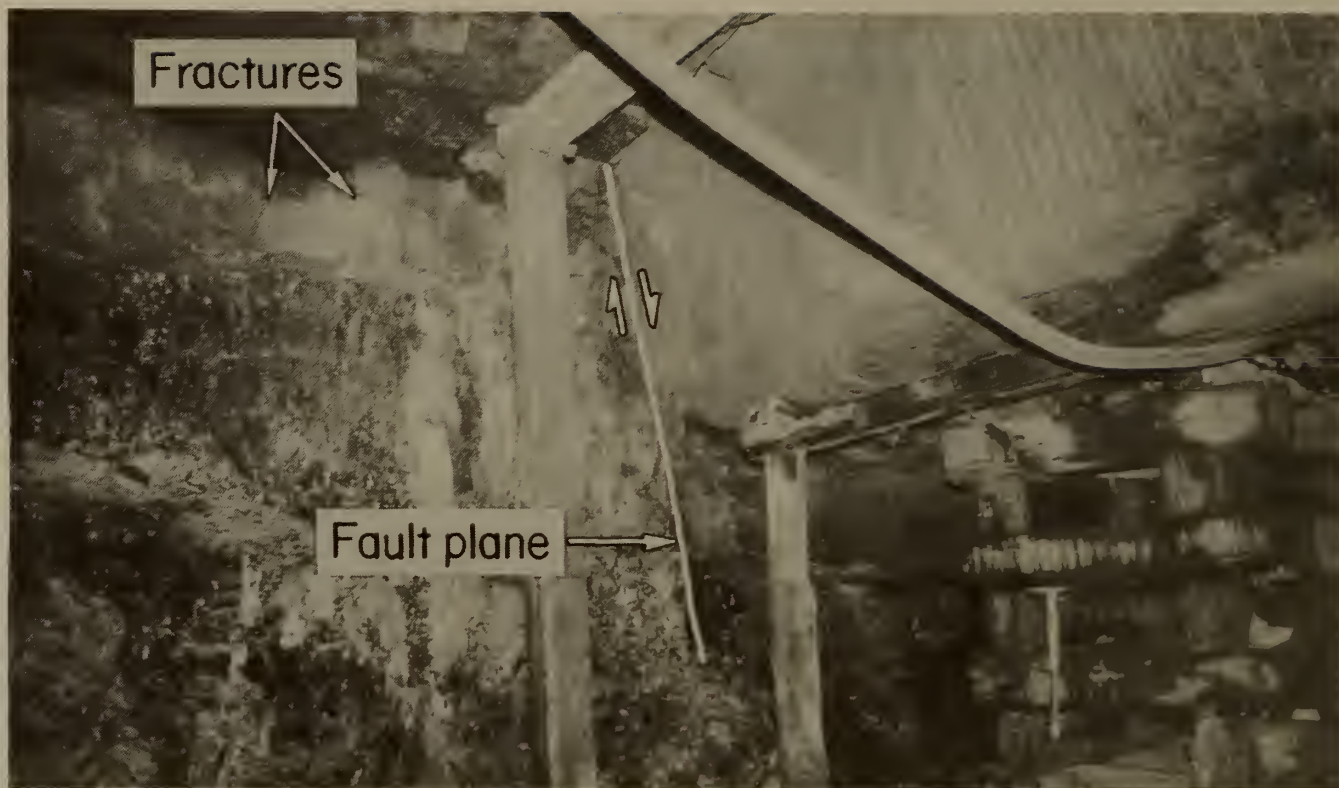


FIGURE 23.—Normal fault (with 3.5 ft of vertical displacement) showing adjacent roof fractures and support.



FIGURE 24.—Normal fault (with approximately 1 ft of vertical displacement) showing little roof disturbance but with evidence of pressure along fault plane.

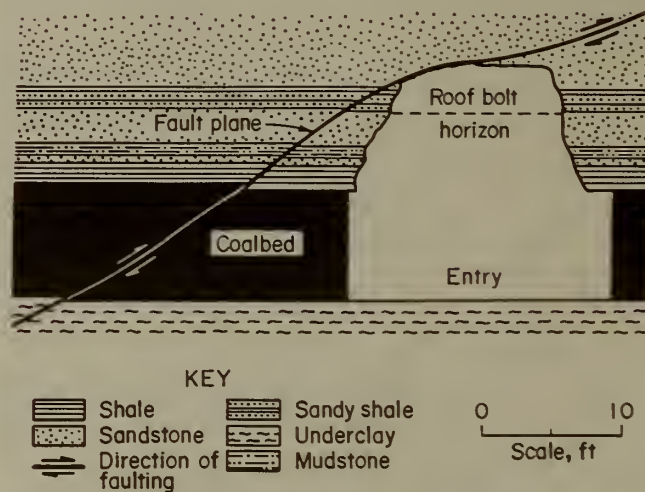


FIGURE 25.—Schematic of low-angle reverse faulting and failure above roof bolt anchorage horizon.



FIGURE 26.—Joint set unrelated to cleat in coalbed.

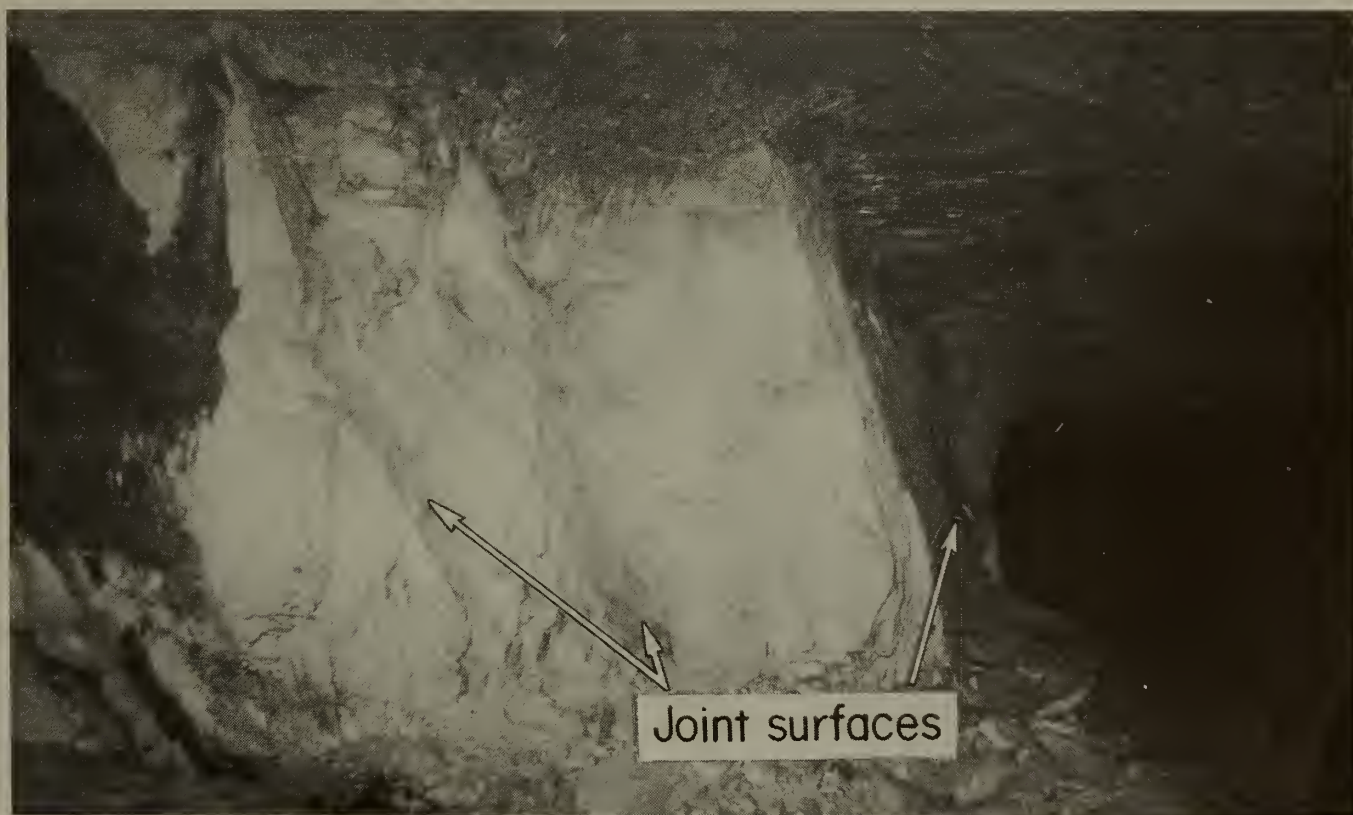


FIGURE 27.—Jointing in coalbed parallel to mining, which has caused pillar slabbing.

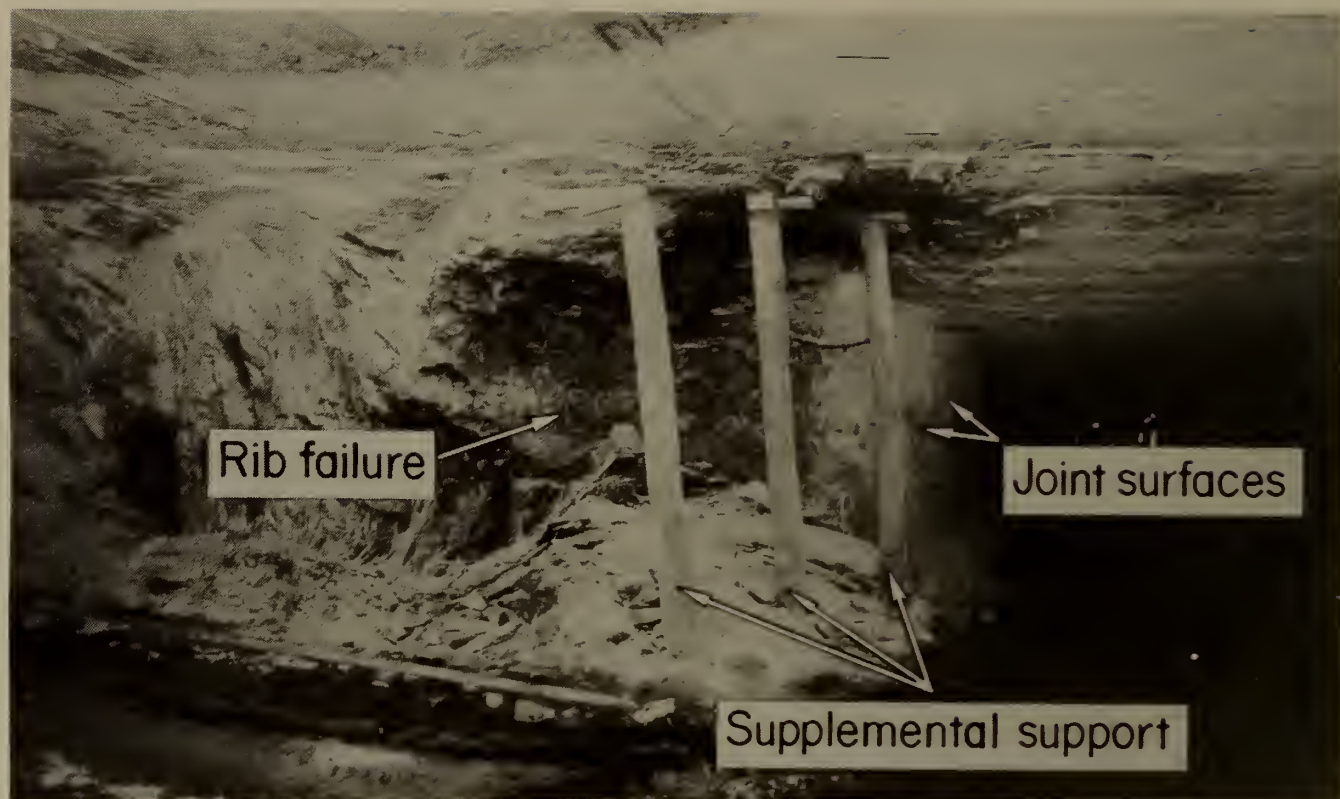


FIGURE 28.—Pillar failure caused by jointing in coalbed.

Jointing in the roof of underground coal mines in the West also contributes to roof instability, probably to a much greater extent than in the East (23). Joints tend to separate the roof into blocks. In roof rock with incohesive bedding, this condition can lead to failure of slabs of rock between support. An example of joint-caused roof failure is given in figure 29. This area of closely spaced joints in the roof was heavily supported with both roof bolts and steel straps. Nonetheless, roof failure occurred between the supports along joint and bedding planes.

FOLDS

A fold is flexure of the rock strata. In western coal fields, folding is gentle to moderate and locally variable. Where folding is gentle, a coalbed may be slightly inclined, and the effect on ground control will be minimal. However, several minable coalbeds in the West are folded more tightly, presenting steeply pitching mining conditions.

Roof control problems associated with folding include fractures, joints, and faults. Jointing can be extensive in the fold crest. Lateral rock movement was noted in the flanks of folds, which, combined with jointing, can cause severe roof instability.

Figure 30 shows a mine working down a fold limb. In this steeply pitching coalbed, movement of workers and machinery is difficult. In this mine, the up-dip floor rock in main entries is being removed to facilitate transportation and haulage.

IGNEOUS DIKES

Igneous dikes are a fairly common occurrence in western coal mines. However, ground control problems associated with them are usually not severe. Igneous dikes are usually found in preexisting fault and joint systems (29). The mine map in figure 22 is a good example of this. Several igneous dikes in this portion of the mine are intruded parallel to the normal faults, presumably along



FIGURE 29.—Small roof fall caused by closely spaced joints.



FIGURE 30.—Haulage entry in steeply pitching coalbed with updip floor rock mined for improved maneuverability.

preexisting planes of weakness. Usually, the high heat flow associated with dikes has created natural coke in the surrounding coal. Figure 31 is a closeup photograph of a dike in a coal rib. The adjacent coal has been converted to coke and exhibits the columnar jointing that is common in slowly cooled rock. Figure 32 shows several parallel igneous dikes intruded into a severely fractured area of a mine. The fractures in this area of the mine are probably the result of the same forces that produced the normal faulting in other areas, and the unstable roof is due more to the fractures than to the igneous dike. Even though igneous dikes are a common occurrence, no coal mines reported any major ground control problems associated with them. They are more a nuisance, creating heavy wear on mining equipment and slowing production.

CLASTIC DIKES

Clastic dikes are intrusive sedimentary features in western coal seams that transect the coal from either above or below.

Most clastic dikes in western coal mines are of a sandstone texture and can enter the coalbed from either the roof or the floor (30). Figure 33 shows a clastic dike that entered the coalbed from below and failed to completely transect it. The clastic dikes observed averaged 2 to 8 in wide, although widths of up to 3 ft were reported. The length of clastic dikes also varies, but dikes have been reported from less than 3 ft to more than 3,000 ft long.

Clastic dikes in western coal mines are not regarded as especially detrimental to ground conditions. In contrast, in eastern coal mines, the weakening effect of clastic dikes extends from 3 to 12 ft above the top of the coalbed. The dikes are generally wedge-shaped masses of slickensided claystone or mudstone filling crevices in the coalbed. In addition to forming a discontinuity in the coalbed and immediate roof, eastern clastic dikes and surrounding rocks are usually heavily slickensided and, therefore, likely to break away from the roof in thick blocks as the supporting coalbed is mined (17).

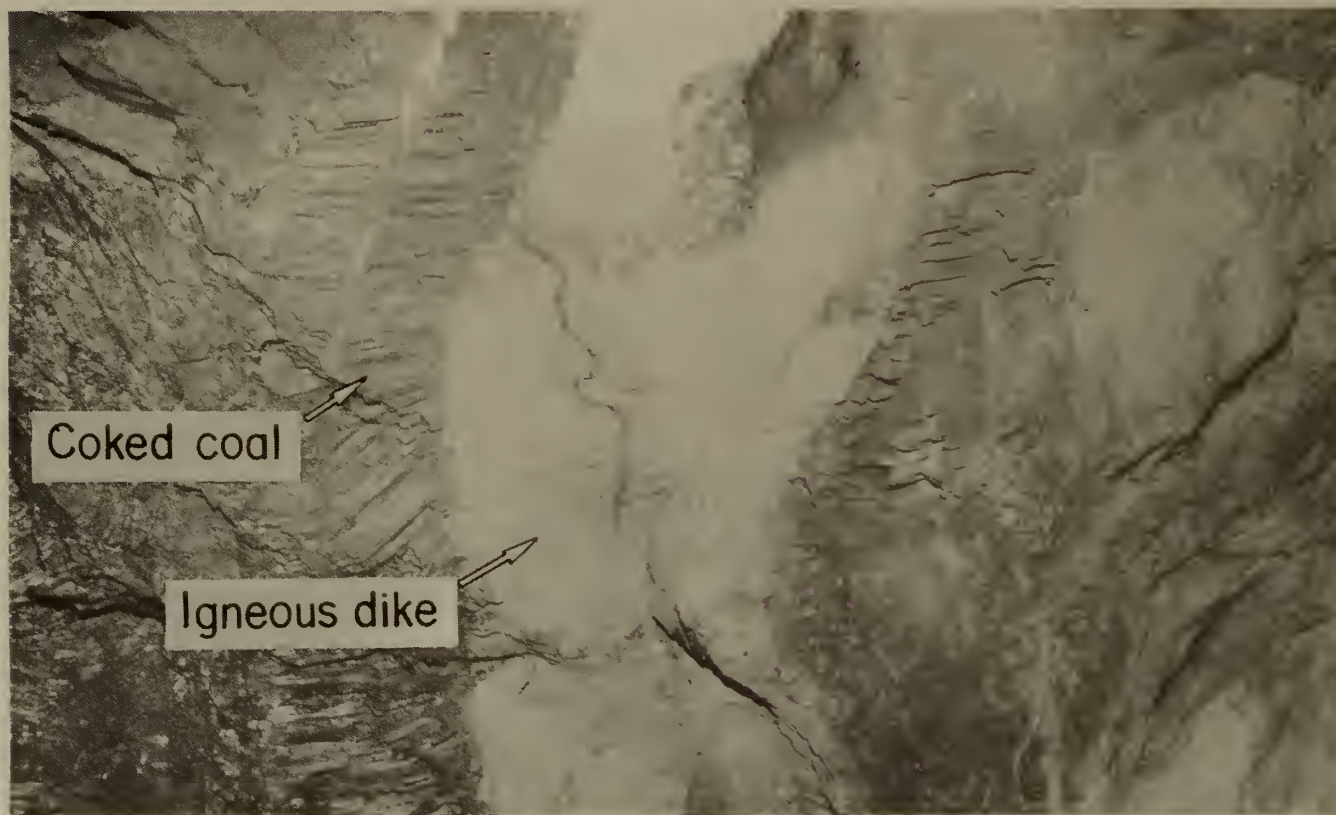


FIGURE 31.—Closeup of igneous dike in coal rib showing effects of heat on coal.

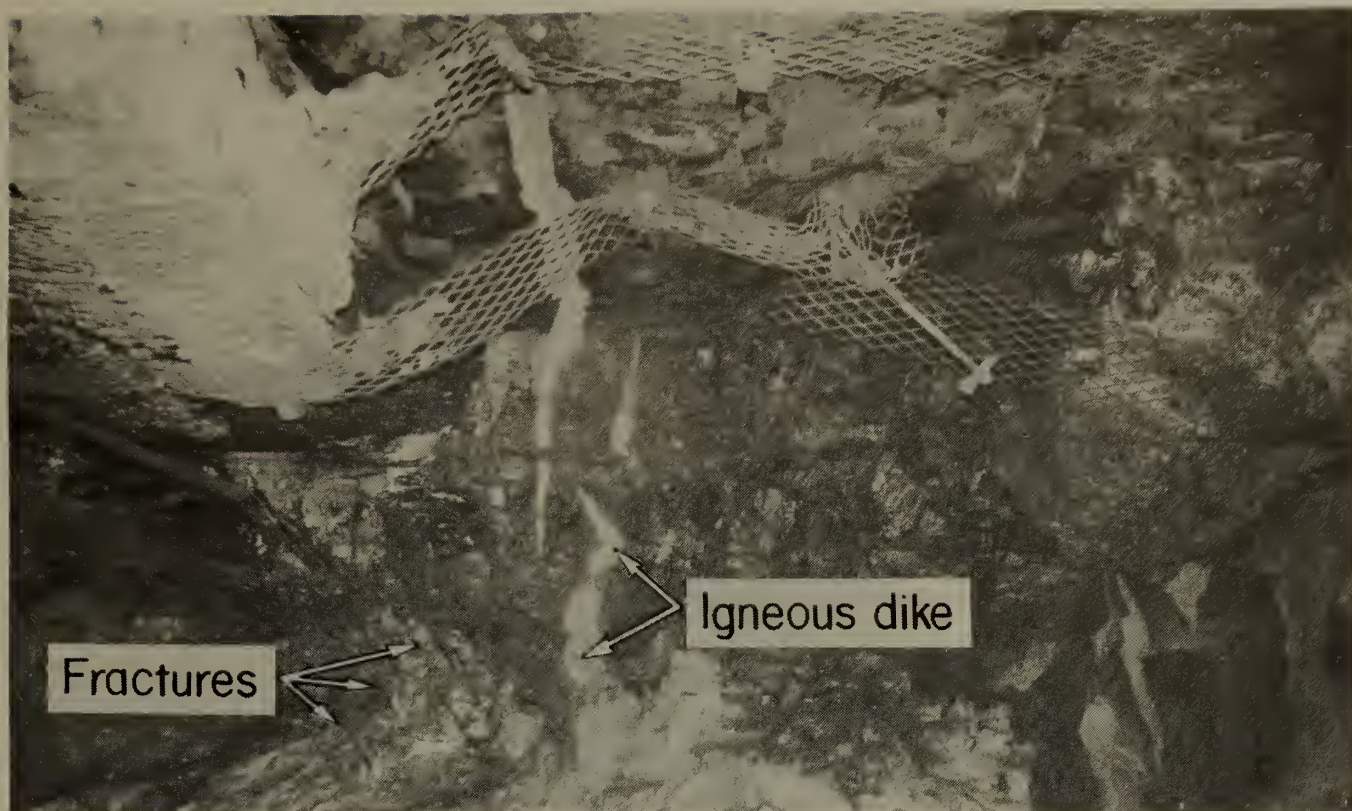


FIGURE 32.—Several discontinuous igneous dikes cutting coalbed, with parallel fracturing in roof rock and coal.



FIGURE 33.—Clastic dike entering coalbed from floor.

Although some reports of clastic dikes causing hazardous roof do occur in the West, most clastic dikes seem to be associated with strong sandstone roof. As is the case with igneous dikes, western

clastic dikes are more of a nuisance, causing heavy wear on mining equipment and slowing production. In addition, they can, in gassy mining conditions, create an ignition source.

DISCUSSION

This geologic study for underground coal mine ground control in the Western United States shows that roof stability is significantly affected by both depositional and structural geologic conditions. The hazardous geologic features do not differ in kind from those commonly found in the East, but they do differ in intensity of occurrence.

Three depositional roof types were found to dominate in unstable roof: paleochannel deposits, which cause the most common and severest roof instability; crevasse splay deposits of thinly interbedded sandstone, siltstone, and mudstone; and swamp and flood basin deposits of thin coals and fine-grained sediments.

Mining hazards associated with paleochannels are slickensided roof rock margins, fractures, mud slips, clastic dikes, coal splitting, distorted bedding or slump deposits, and water. Hazards associated with crevasse splays are delamination of the roof and failure above the roof bolt anchorage horizon. Also, increased instability was observed in crevasse splay roof as overburden thickness increased. Flood basin deposits contain many common mining hazards, including slickensides, kettlebottoms, rider seams, deterioration from moisture, and fissile bedding.

Hazardous structural geologic conditions occurring in western underground coal mines are not so widespread or common as the identified depositional hazards. The most commonly encountered structural hazards are faults and joints. Folds, while not as common as faults or joints, can also present serious mining

difficulties. Two other structural hazards that cause fewer ground control problems, but are often encountered, are igneous and clastic dikes.

Minor to severe ground control problems are associated with faults. The coalbed can be completely offset, requiring rock tunneling through fractured rock to re-enter the mining horizon. More commonly, the offsets are small, normal displacements that fracture the surrounding roof rock. Joints in the roof strata break the roof span, making support difficult. Joints in the coalbed cause rib instability that can lead to roof failure. Folding of the strata causes pitching seam conditions, lateral rock movement in the roof, and difficulty in movement of workers and machinery. Igneous dikes, while not always causing severe roof conditions, can weaken the roof with associated fracturing. Clastic dikes also have associated fracturing and slickensides that weaken the roof and make ground support difficult.

This report describes the initial phase of a program intended to provide background geologic information on western coalfields, to define and describe the geologic features and adverse conditions that create ground control problems, and to characterize the behavior of these features in response to mining. While the scope of this report is limited to a preliminary survey, it provides guidance for further study into the prediction of these geologic hazards, and the development of roof support requirements for effective ground control in mines.

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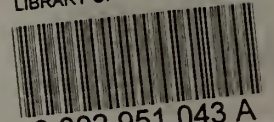
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